POLARIZING RADIATION FROM TARGETS WITH FINITE SIZES

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In the present report models of generation of the diffractional and Cherenkov radiation under a overflight of a charged particle around a rectangular shield and a triangular prism with arbitrary conductivity are submitted. In the process of researching different types of relations of geometric and macroscopic features of target and polarizing radiation were identified – such as dependents of intensity of radiation from depth of the shield, from value of dielectric permeability, from the value of impact-parameter, etc. The method of surface currents was used to make a mathematical model of the process of generation of the polarizing radiation.

Key words: polarizing radiation, Vavilov-Cherenkov radiation, diffraction radiation.

Research field: classical electrodynamics.

Related sciences: nuclear physics, physics of elementary particles.

INTRODUCTION

Nowadays theory of the emission of charged particles is not only dynamically developing field of the theoretical physics, but also it has multiple practical applications in the accelerator physics, plasma physics, the ultra-high frequency electronics. For example, since the 90s of the last century interest to transition radiation (TR) and diffraction radiation (DR) has grown significantly, because this radiation can be used in methods of weak-perturbing diagnostics of low-emittance beams in accelerators. This interest is primarily conditioned by the fact, that losses of energy of a particle with TR and DR are negligibly small versus the full energy of the particle [1]. In fact, these types of radiation represent different forms of polarizing radiation (PR), which have physical reason in dynamic polarization of atoms of the media by charged particle. In this case it is usually talked about the radiation of uniformly and rectilinearly moving charge (as well as in case of Vavilov-Cherenkov radiation), and both particle and excited atoms of the media can be called as source of radiation, since either of components is necessary for emergence of the radiation.

Polarizing radiation is a name for radiation that appears when moving charged particles interact with a condensed surroundings. Every charged particle creates around itself a spherically symmetric electric field. When it moves with a relativistic velocity, field will be deformed by the reason of the Lorenz-effect (reduction of a length in the direction of movement and enlargement a length in other directions) [2]. Flying near any atomic structure, particle will interact with electrons from outer energy levels by its field. As a result of this interplay, displacement of orbits of electrons occurs. Atom becomes polarized. Electronic shell will try to back in the normal condition and start to hover. These oscillations are cause for emission of polarizing radiation.

There are some types of PR: Vavilov-Cherenkov radiation (ChR), transition radiation, diffraction radiation and Smith-Purcell radiation (SPR).

The aim of this work is to research the properties of the polarizing radiation, which is generated by a charged particle provided flight near the rectangular screen or triangle prism with finite sizes, depending on geometric and macroscopic parameters of the target.

Objectives: look for theoretical approach of polarizing radiation, learn about the method of surface currents, build a mathematical model of process of polarizing radiation, test it for some special cases.

METHODOLOGY [6]

For mathematical modeling of process of the PR method of surface currents were used.

The surface current method is known in the theory of electromagnetic waves diffraction and it has been generalized to be applied to the problems of diffraction radiation generated by a charged particle moving nearby a screen in vacuum.

The exact macroscopic theory of plane waves diffraction is based on the use of the well-known integral equation for the surface current density induced by an incident field. In the last case the incident field satisfies the inhomogeneous Maxwell's equations. This rather unexpected fact may be explained taking into account the derivation of the integral equation using the so-called double-current layer formulation. On the other hand, this formulation allows finding the new integral equations determining a surface current density in the case when the incident field is not a plane wave. Solutions of these generalized equations allow to find the surface current density, and therefore to find an exact solution of a problem.

Physically, when a field (no matter what its nature) falls on a screen with unit normal **n** it induces a dipole moment resulting in appearance of an additional field. In other words, the scattered wave may be represented as a field of the surface current formed by the dipoles distributed on a screen. Such representation corresponds to the ordinary dipole approximation in the microscopic theory of polarizing radiation. The surface distribution of electric dipole moment is known as a double sheet (layer), which is a surface where the density of surface charges $\rho_e \propto \mathbf{n}\cdot\mathbf{E}$ changes its sign but preserves its absolute value. The corresponding Maxwell's equations for the double surface current density may be written as:

$$\mathbf{E}(\mathbf{r},\omega) = \frac{\mathrm{ic}}{\omega}(\mathrm{grad}(\mathrm{div} + \frac{\omega^2}{\mathrm{c}^2}))\mathbf{A}, \qquad \mathbf{H}(\mathbf{r},\omega) = \mathrm{rot}\mathbf{A},$$

$$\mathbf{A} = \frac{1}{\mathrm{c}}\int \mathbf{j}_s^e(\mathbf{r}',\omega)\frac{e^{i\omega|\mathbf{r}-\mathbf{r}'|/c}}{|\mathbf{r}-\mathbf{r}'|}\mathrm{dS}', \quad \mathbf{j}_s^e = \frac{c}{2\pi}\mathbf{n}\times\mathbf{H},$$

where the dependence of current in the right-hand side upon the field in the left-hand side makes them integral equations for fields.

There also another method may be used, where a sign of the surface electric charges does not change when crossing the screen, but a sign of magnetic charges $\rho_m \propto \mathbf{n}\cdot\mathbf{H}$ changes. This representation leads to the dual Maxwell's equations for the double magnetic surface current density:

$$\mathbf{H}(\mathbf{r},\omega) = \frac{\mathrm{ic}}{\omega}(\mathrm{grad}(\mathrm{div} + \frac{\omega^2}{\mathrm{c}^2}))\tilde{\mathbf{A}}, \qquad \mathbf{E}(\mathbf{r},\omega) = -\mathrm{rot}\tilde{\mathbf{A}},$$

$$\tilde{\mathbf{A}} = \frac{1}{\mathrm{c}}\int \mathbf{j}_s^m(\mathbf{r}',\omega)\frac{e^{i\omega|\mathbf{r}-\mathbf{r}'|/c}}{|\mathbf{r}-\mathbf{r}'|}\mathrm{dS}', \qquad \mathbf{j}_s^m = -\frac{c}{2\pi}\mathbf{n}\times\mathbf{E},$$

and corresponds to a double magnetic sheet, where the "current density" (axial vector) $\mathbf{j}^{\mathbf{m}}_{\mathbf{s}}$ is formed by magnetic dipoles. The problem of a plane wave diffraction on a screen with permittivity ε= ∞ is known to be equivalent to the problem of diffraction on a complementary screen with $\mu = \infty$.

The fields in the right-hand sides of the last equals consist of the incident fields **H**i , **E**i and the scattered ones **H**s, **E**s , while the fields in the left-hand side are commonly observed at the far distances where only the scattered field has place (wave zone). Substituting the expression for magnetic field in the surface current, it is possible to write down the ordinary Fock's integral equation for the current density:

$$\mathbf{j}_s^e(\mathbf{r}',\omega) = \frac{c}{2\pi}\mathbf{n}\times\mathbf{H}_i - \frac{1}{2\pi}\mathbf{n}\times\int \mathbf{j}_s^e(\mathbf{r}'',\omega)\times \mathrm{grad}\,\frac{e^{i\omega|\mathbf{r}-\mathbf{r}''|/c}}{|\mathbf{r}-\mathbf{r}''|}\,dS''.$$

DEVELOPMENT

Schemes of generation PR in the case of screen (Fig. 2) and prism (Fig. 3) are shown.

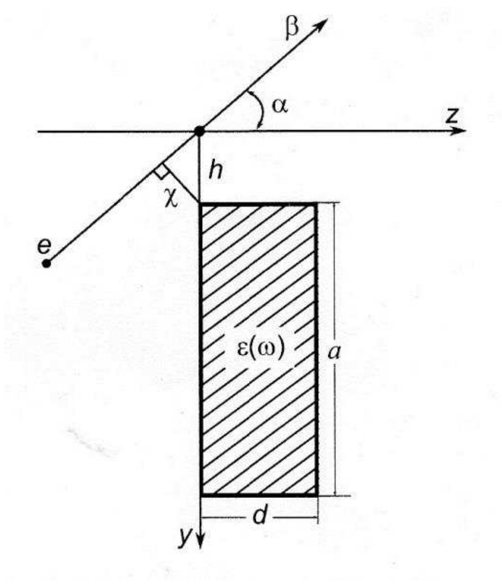


Fig. 2. Scheme of generation of PR from the screen

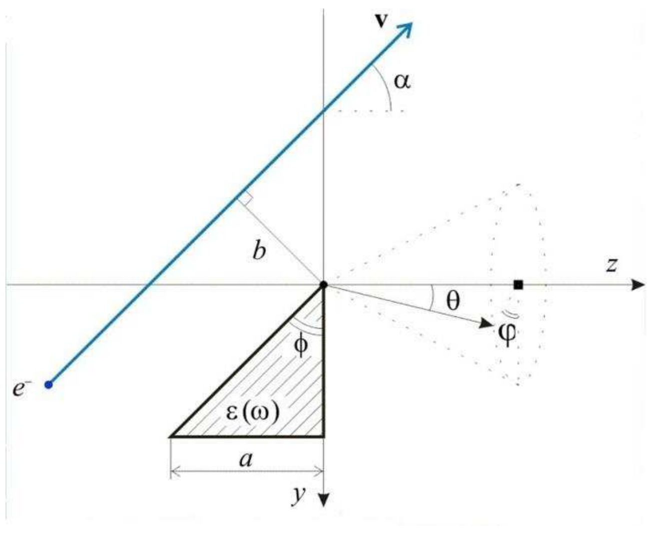
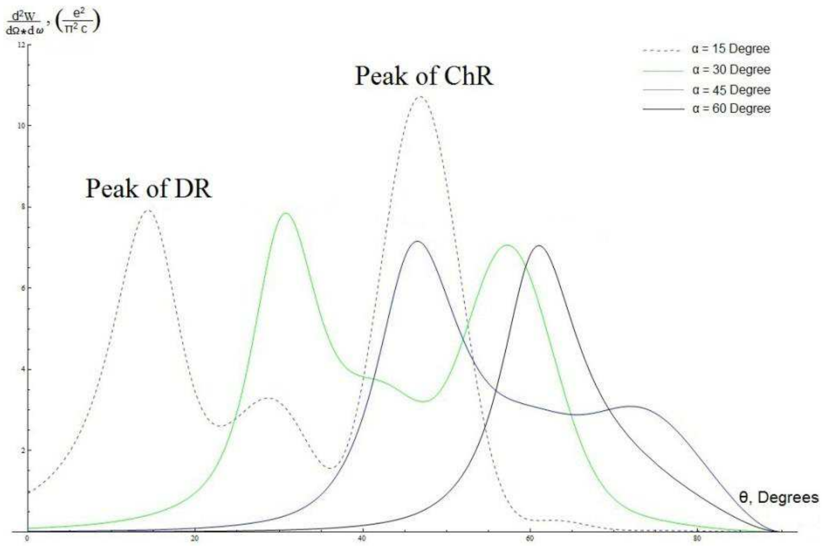


Fig. 3. Scheme of generation of PR from the prism

Where χ (or b) – impact-parameter (the shortest distance between the edge of the target and trajectory of the particle); h – distance from the origin to the target; γ – Lorenz-factor; v – velocity of the particle; c – speed of light in vacuum; β – relative velocity of particle; d – depth of the target; a – length of the target; θ – polar angle, α – angle of flight of the particle; φ – azimuth angle; $\varepsilon = \varepsilon' + i\varepsilon''$ – permittivity of the media (target); ω – frequence of the polarizing radiation, λ – wavelenght of the polarizing radiation, ϕ – angle of diclosure of the prism.

As example, the dependence between spectral-angular density of PR from the polar angle over the different angles of flying is descried.



Parameters: $c = 3*10^8$mps; $\gamma = 10$; $\varepsilon = 1.5 + 0*i$; $\chi = 10^{-3}$m; d = 10^{-2}m; a = 0.005 m; $\phi = 180°$; $\lambda = 0.001$ m.

Fig. 4. Dependence between spectral-angular density of PR from the polar angle over the different angles of flying

As we can see, under the low angles of fall intensity of DR is small, ChR makes primary contribution. When the angle α grows, peak of the ChR replaces in the side of bigger polar angles and, at the same time, its intensity descends, and, when $\alpha = 60°$, only DR makes the principal contribution.

The peak of DR behaves similar way, i.e. it moves in the region of bigger polar angles θ, but decrease of intensity of this radiation goes more smoothly.

RESULTS

In the present paper models of generation of the TR and DR are presented in the case of flying of charged particle near the rectangular screen and triangular prism with an arbitrary conductivity. These models can be used for the solution of problems of generation THz-radiation with short relativistic electron clots and for elaboration of the new methods of diagnostic of charged particle beams by the modern accelerators.

In the process of researching some dependences has been found, that correspond to the relations between characteristics of DR, which is excited by relativistic particle over the flying near screen and prism, and thickness of the screen, the dielectric permittivity, the impact-parameter. In the case of zero width of the slot results fully coincide with the respective results from the theory of TR for plate with arbitrary values of permittivity and angle of the fall were obtained. Obtained equations for the spectral-angular density of radiation in the backwards direction explain not only mechanism of DR, but also Vavilov-Cherenkov radiation.

Thus, dependencies of the main properties of different types of polarizing radiation (DR, TR, ChR, other) from geometric, macroscopic characteristics of the target, from the parameters of the particles, that cause present radiation, has been determined.

CONCLUSION

It is clear, therefore, that area of application of polarizing radiation significantly has enlarged nowadays. Theories about fundamental structure and variable effect of emitting are successfully constructed, technological progress opens new horizons for researching and using polarizing radiation.

The most popular direction in the modern physics is elementary particles. They are analyzed and dissected in the colliders, and the DR helps to diagnose beams of particles and make courageous experiments possible. Transition radiation is used in such important method of science as microscopy.

REFERENCES

1. Tyapkin, A.A. (2001) Microscopic nature underlying Vavilov-Cherenkov effect. Physics of atomic nucleus and elementary particles, 32 (4), 946 – 963.
2. Landau, L.D., Lifshitz, E.M. Theoretical physics, vol. 8: Electrodynamics of Continuous Media: Handbook (Nauka, Moscow, 1982), p.211.
3. Jelly, J.V. (1956) Cherenkov Radiation. UFN, 58 (2), 232 – 283.
4. Bolotovsky, B.M., Galstyan, E.A. (2000) Diffraction and diffraction radiation. UFN, 170 (8), 809 – 830.
5. Carlovets, D.V., Potylistin, A.P. (2008) On the theory of diffraction radiation. JETP, 134 (5), 887 – 901.
6. Karlovets, D.V., Potylitsyn, A.P. (2009) Generalized surface current method in the macroscopic theory of diffraction radiation. Physics Letters A, 373, 1988-1996.
7. Jackson, J.D. Classical electrodynamics: Handbook (John Wiley & Sons, Inc., New York – London, 1962), p.130.